The Business Case for Systems Engineering: Comparison of Defense-Domain and Non-Defense Projects

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The Software Engineering Institute (SEI)
a DoD Research FFRDC

		Form Approved OMB No. 0704-0188

Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **27 OCT 2014**	2. REPORT TYPE **N/A**	3. DATES COVERED

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The Business Case for Systems Engineering: Comparison of Defense-Domain and Non-Defense Projects	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Elm /Joe**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Software Engineering Institute Carnegie Mellon University Pittsburgh, PA 15213**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**31**	

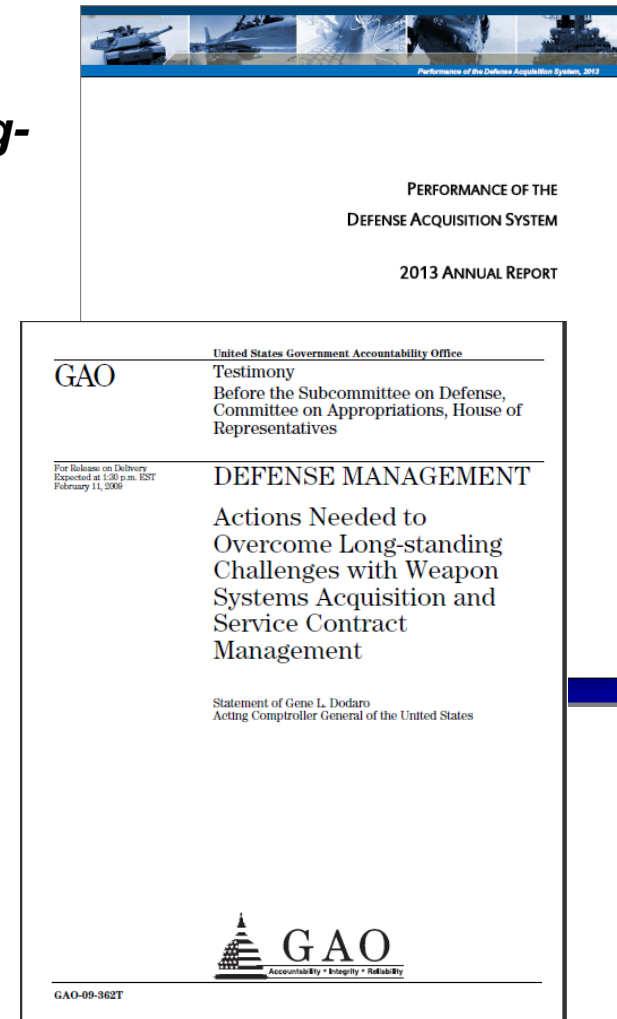**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

Challenges in DoD Acquisition

GAO-09-362T - Actions Needed to Overcome Long-standing Challenges with Weapon Systems Acquisition and Service Contract Management

- "costs … increased 26% and development costs increased by 40% from first estimates"

- "programs … failed to deliver capabilities when promised —often forcing warfighters to [maintain] legacy systems"

- "current programs experienced, on average, a 21-month delay in delivering initial capabilities to the warfighter"

Although DoD is the largest acquirer in the world, acquisition troubles remain [1]

- 2011 MDAP RDT&E cost growth (mean)   84%
- 2011 MDAP Procurement cost growth (mean)   28%
- Effectiveness (1984-2011)   89%
- Suitability (1984-2011)   72%
- Nunn-McCurdy breach rate from 1997-2011   31%

PERFORMANCE OF THE DEFENSE ACQUISITION SYSTEM

2013 ANNUAL REPORT

United States Government Accountability Office

GAO

Testimony
Before the Subcommittee on Defense, Committee on Appropriations, House of Representatives

For Release on Delivery
Expected at 1:30 p.m. EST
February 11, 2009

DEFENSE MANAGEMENT

Actions Needed to Overcome Long-standing Challenges with Weapon Systems Acquisition and Service Contract Management

Statement of Gene L. Dodaro
Acting Comptroller General of the United States

GAO
Accountability * Integrity * Reliability

GAO-09-362T

1.   "Performance of the Defense Acquisition System 2013 Annual Report" Table 2-3, page 34)

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NDIA

AESS

Root Cause of Poor Program Performance

Inadequate Systems Engineering!

- Finding from *Performance of the Defense Acquisition System 2013 Annual Report*

  - **Dominant root cause** of MDAP Cost Growth

- Finding from *GAO-09-362T*

  - "… managers rely heavily on assumptions about system requirements, technology, and design maturity, which are consistently too optimistic. These gaps are largely the result of a **lack of a disciplined systems engineering analysis** prior to beginning system development …"

MDAP Cost Growth: PARCA Root Cause Analysis[1]

Dominant	
10 of 18 (56%)	**Poor management performance** • **Systems engineering** • Contractual incentives • **Risk management** • Situational Awareness
5 of 18 (28%)	**Baseline cost and schedule estimates** • **Framing assumptions**
4 of 18 (22%)	**Change in procurement quantity**
Infrequent	
1 of 18	**Immature technology, excessive manufacturing, or integration risk**
2 of 18	**Unrealistic performance expectations**
1 of 18	**Unanticipated design, engineering, manufacturing or technology issues**
None	**Funding inadequacy**

1. "Performance of the Defense Acquisition System 2013 Annual Report" Table 2-3, page 34*)*

Why Do We Fail to Utilize Good SE Practices?

It's difficult to justify the costs of SE in terms that project managers and corporate managers can relate to.

- The costs of SE are evident
  - Cost of resources
  - Schedule time

- The benefits are less obvious and less tangible
  - Cost avoidance (e.g., reduction of rework from interface mismatches)
  - Risk avoidance (e.g., early risk identification and mitigation)
  - Improved efficiency (e.g., clearer organizational boundaries and interfaces)
  - Better products (e.g., better understanding and satisfaction of stakeholder needs)`

> **We need to quantify the effectiveness and value of SE by examining its effect on project performance?**

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BCSE: Defense vs. Non-Defense Projects
27-Oct-2014

5

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The 2012 SE Effectiveness Study

Purpose

- Strengthen the business case for SE by relating project performance to the use of SE practices.

Method

- Contact development projects using the resources of NDIA, AESS, and INCOSE.
- Survey projects to assess their
  - SE activities
  - Project performance
  - Degree of challenge
- Process responses to identify statistical relationships between parameters.

Survey Tenets

- All data is submitted anonymously and handled confidentially by the SEI.
- Only aggregated non-attributable data is released.

BCSE: Defense vs. Non-Defense Projects
27-Oct-2014

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The Bottom Line: SE = Performance

Program Performance vs. Total SE

Gamma = 0.49   p-value < 0.001

Across ALL projects, 1/3 are at each performance level

For **Lower SEC** projects, only **15% deliver** higher performance

For **Middle SEC** projects, **24%** deliver higher performance

For **Higher SEC** projects, 57% deliver higher performance

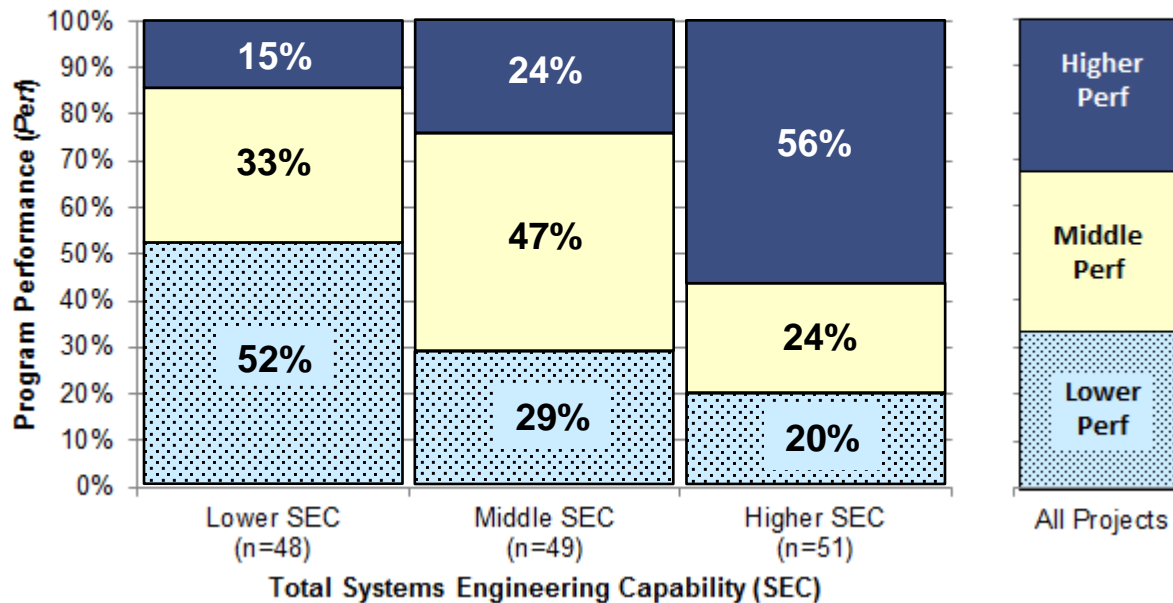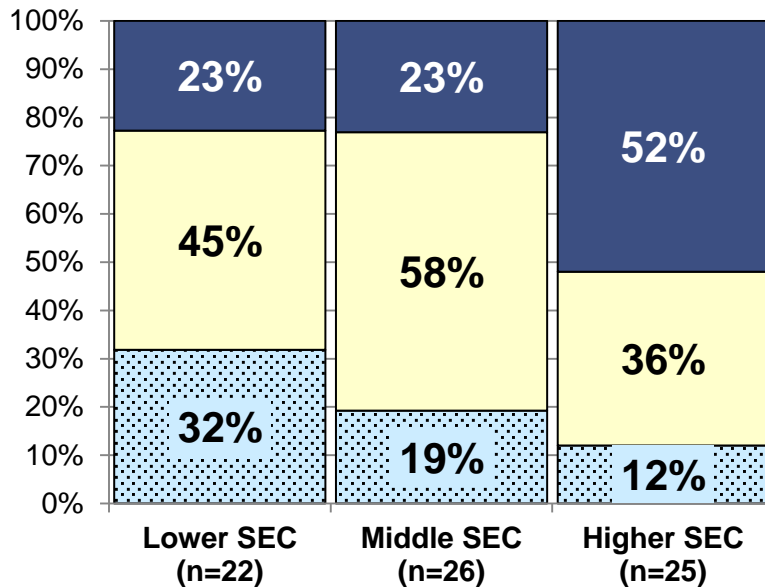**Gamma = 0.49 represents a VERY STRONG relationship**

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For Challenging Projects SE is even MORE important

Perf vs. SEC_Total (Low PC)

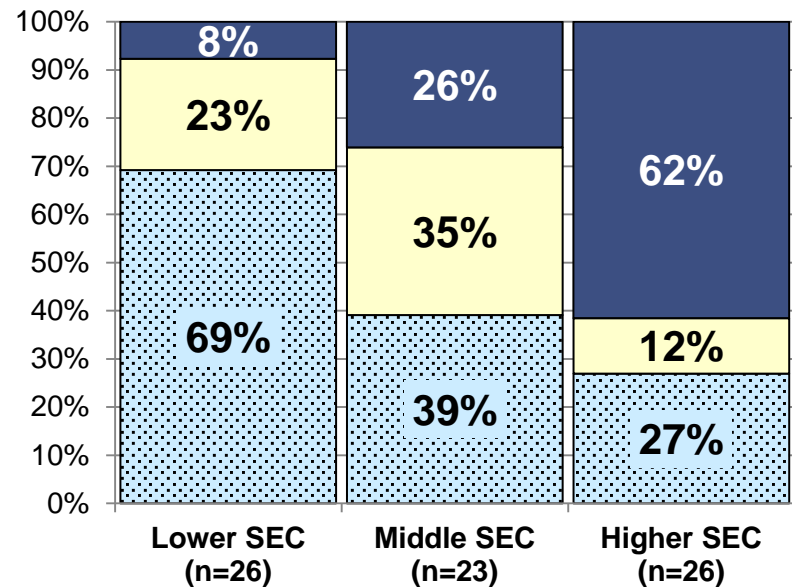|	Lower SEC (n=22)	Middle SEC (n=26)	Higher SEC (n=25)
Top (dark)	23%	23%	52%
Middle (yellow)	45%	58%	36%
Bottom (light)	32%	19%	12%

Gamma = 0.34	p-value = 0.029

A STRONG relationship between Total SE and Project Performance for LOWER CHALLENGE projects

Perf vs. SEC_Total (High PC)

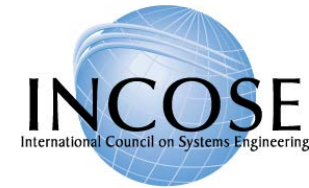|	Lower SEC (n=26)	Middle SEC (n=23)	Higher SEC (n=26)
Top (dark)	8%	26%	62%
Middle (yellow)	23%	35%	12%
Bottom (light)	69%	39%	27%

Gamma = 0.62	p-value = 0.000

A VERY STRONG relationship between Total SE and Project Performance for HIGHER CHALLENGE projects
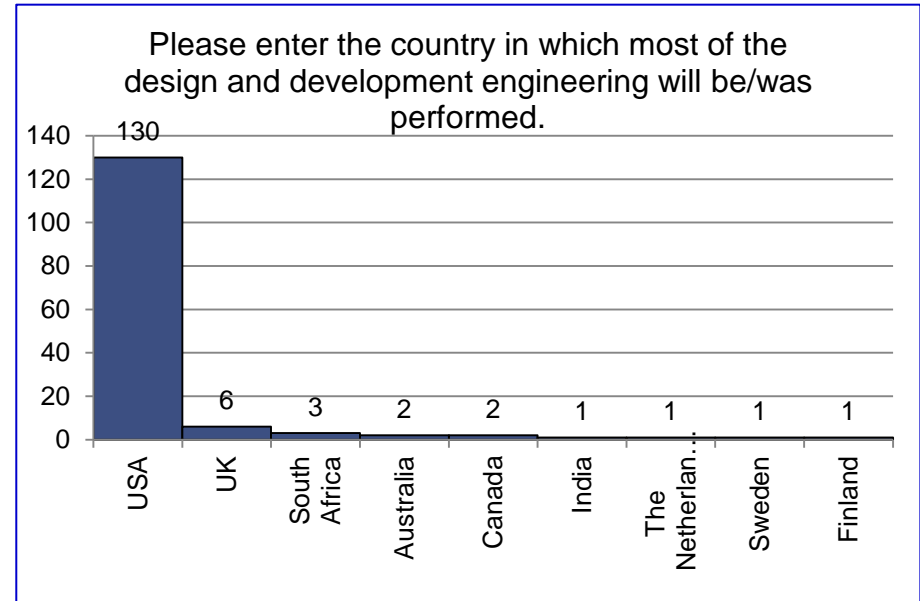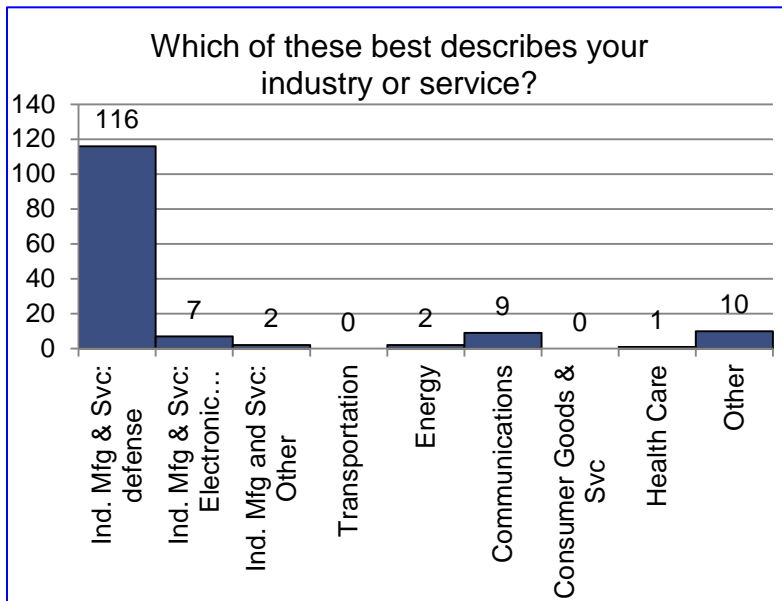
Study Participants

Participant Solicitation

- Contacted key members of major defense contractors to promote study participation

- Contacted the memberships of NDIA SE Division, IEEE AESS, and INCOSE

Collected 148 valid responses

Which of these best describes your industry or service?

Category	Value
Ind. Mfg & Svc: defense	116
Ind. Mfg & Svc: Electronic…	7
Ind. Mfg and Svc: Other	2
Transportation	0
Energy	2
Communications	9
Consumer Goods & Svc	0
Health Care	1
Other	10

Please enter the country in which most of the design and development engineering will be/was performed.

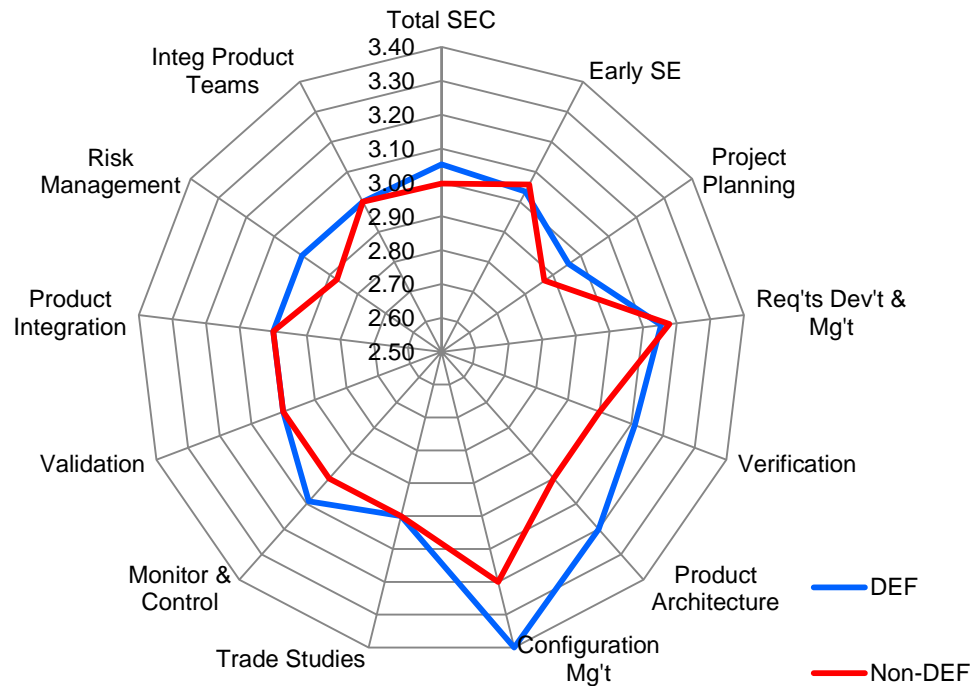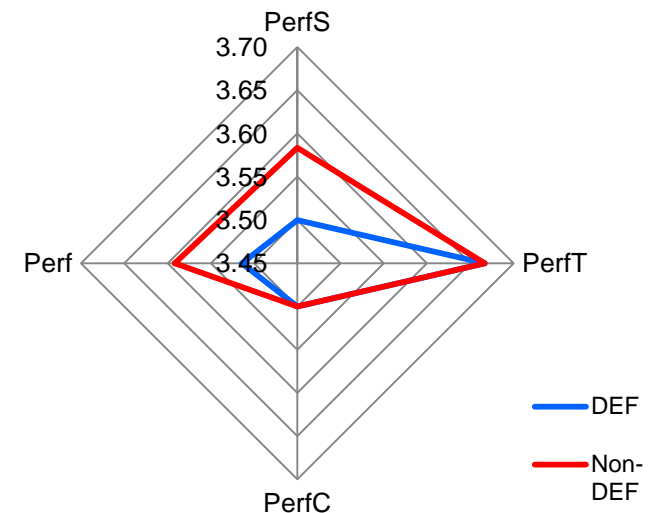| Country	Value
USA	130
UK	6
South Africa	3
Australia	2
Canada	2
India	1
The Netherlan…	1
Sweden	1
Finland	1

SE Deployment and Performance

SYSTEMS ENGINEERING DEPLOYMENT

PROJECT PERFORMANCE

Total SE vs. Project Performance

Project Performance vs. Total SE (defense)

Lower SEC (n=23): 9% / 30% / 61%
Middle SEC (n=26): 35% / 42% / 23%
Higher SEC (n=26): 54% / 31% / 15%

Total Systems Engineering Capability (SEC)

Legend:
- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Gamma = 0.57
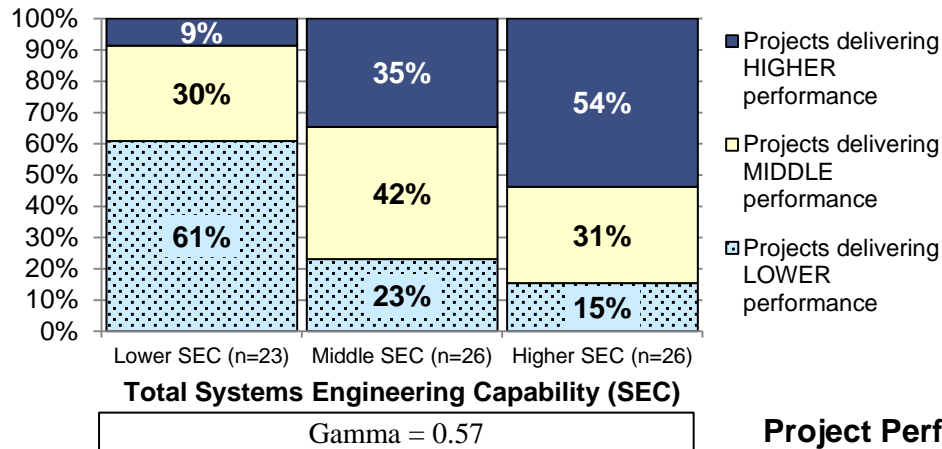
A **Very Strong** relationship between applied SE and Project Performance for both Defense and non-Defense Projects

Project Performance vs. Total SE (non-defense)

Lower SEC (n=12): 8% / 25% / 67%
Middle SEC (n=8): 25% / 38% / 38%
Higher SEC (n=11): 55% / 36% / 9%

Total Systems Engineering Capability (SEC)

Legend:
- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Gamma = 0.66
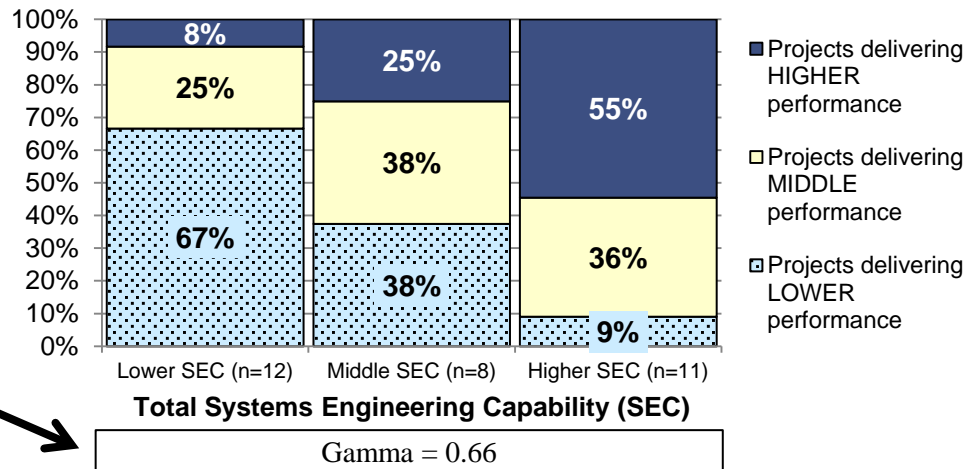
Architecture vs. Project Performance

Perf vs. SEC_ARCH (defense)

Chart: Perf vs. SEC_ARCH (defense), SE Deployment

	Lower SEC (n=19)	Middle SEC (n=33)	Higher SEC (n=23)
HIGHER	16%	33%	48%
MIDDLE	37%	33%	35%
LOWER	47%	33%	17%

- ■ Projects delivering HIGHER performance
- □ Projects delivering MIDDLE performance
- ▨ Projects delivering LOWER performance

Gamma = 0.38
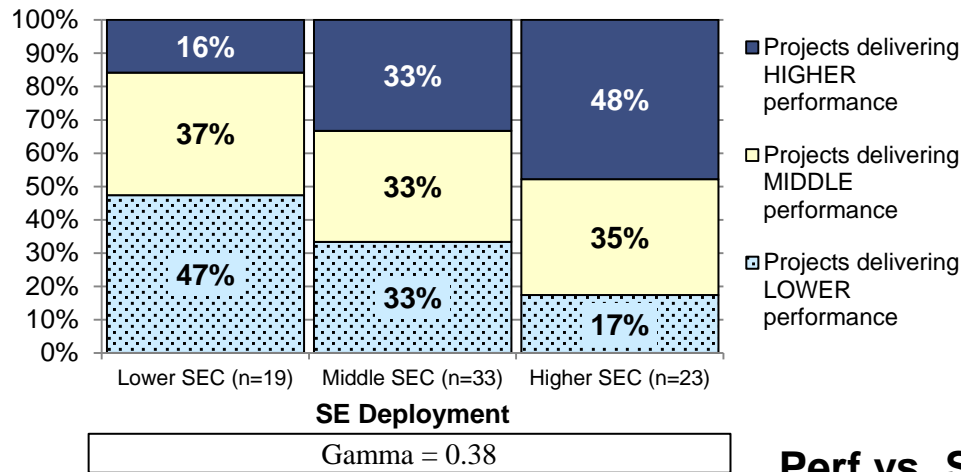
A **Strong** relationship between Architecture activities and Project Performance for Defense Projects

A **Very Strong** relationship for non-defense projects

Perf vs. SEC_ARCH (non-defense)

Chart: Perf vs. SEC_ARCH (non-defense), SE Deployment

	Lower SEC (n=14)	Middle SEC (n=6)	Higher SEC (n=11)
HIGHER	14%	33%	45%
MIDDLE	29%	33%	36%
LOWER	57%	33%	18%

- ■ Projects delivering HIGHER performance
- □ Projects delivering MIDDLE performance
- ▨ Projects delivering LOWER performance

Gamma = 0.54

Requirements Dev't & Mg't vs. Performance
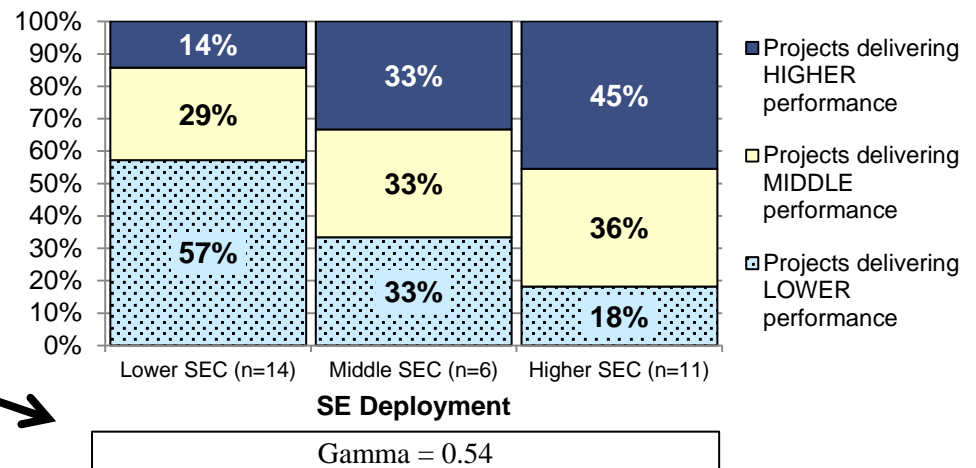
Perf vs. SEC_REQ (defense)

Gamma = 0.46

A **Very Strong** relationship between Requirements activities and Project Performance for both Defense and non-Defense Projects

Perf vs. SEC_REQ (non-defense)

Gamma = 0.6

Risk Management vs. Project Performance

Perf vs. SEC_RSKM (defense)

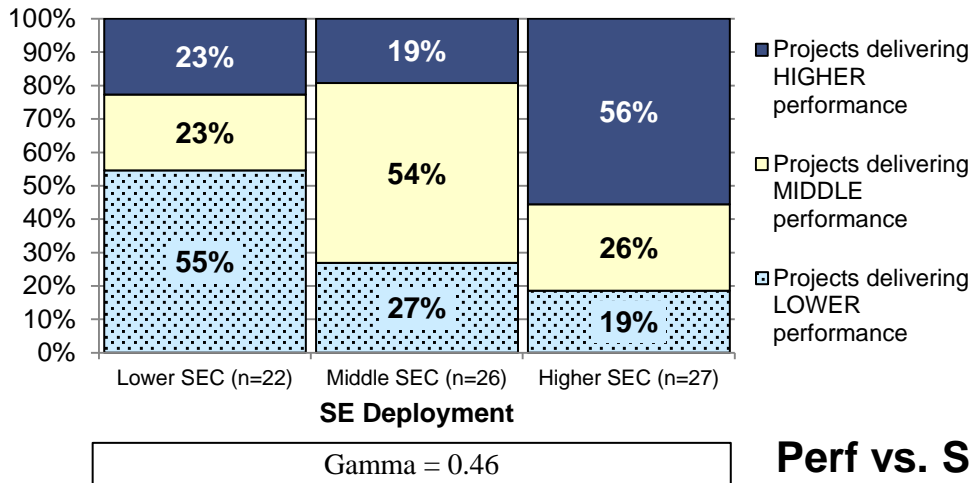A **Moderate** relationship between Risk Management activities and Project Performance for Defense Projects

A **Very Strong** relationship for non-defense projects
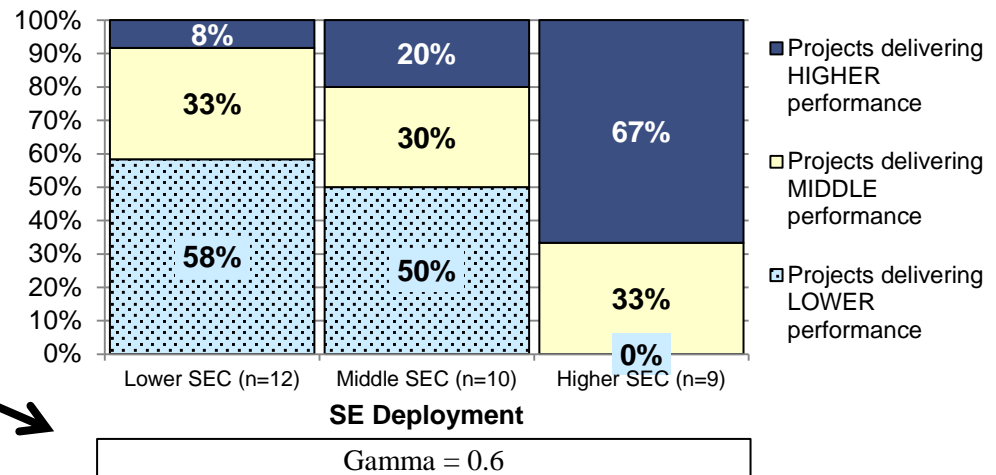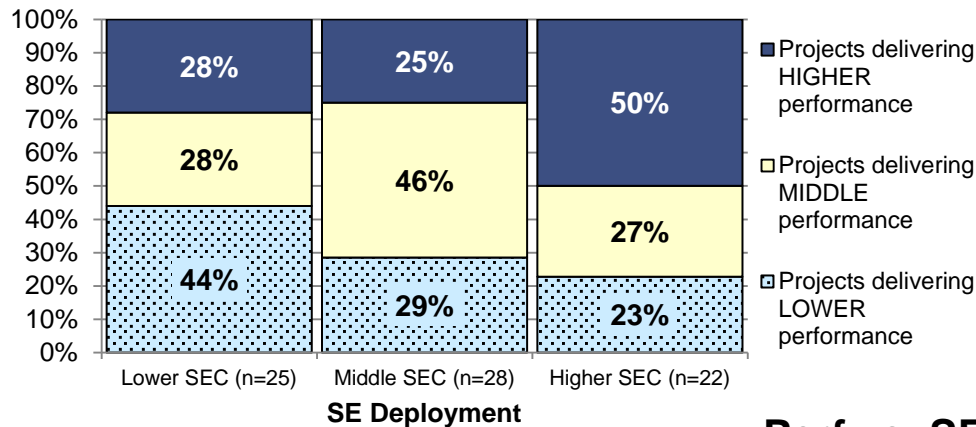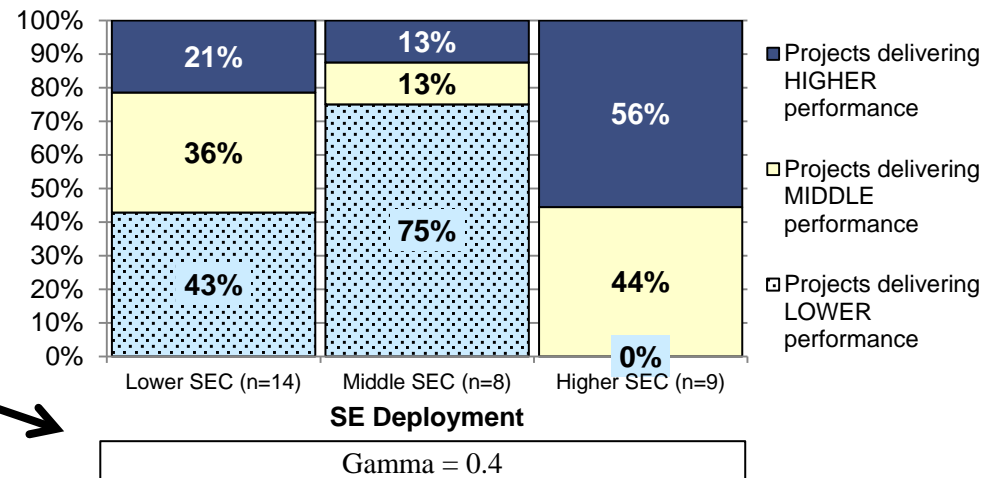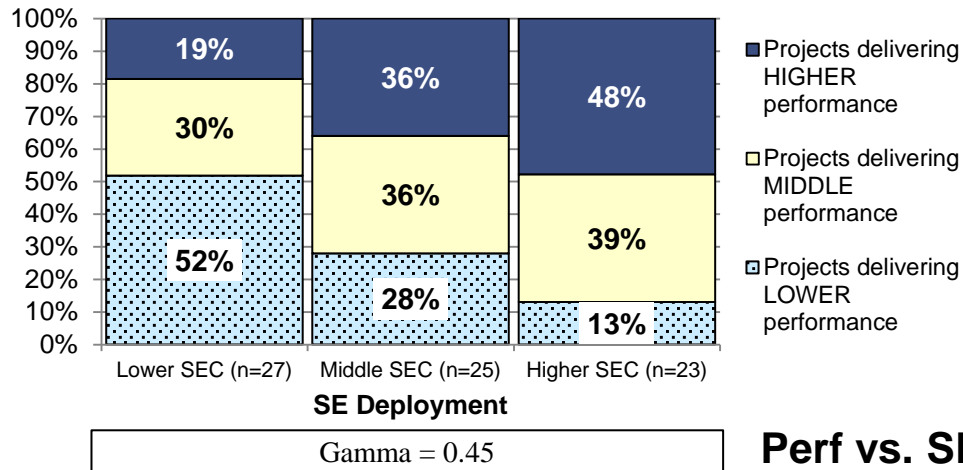
Perf vs. SEC_RSKM (non-defense)
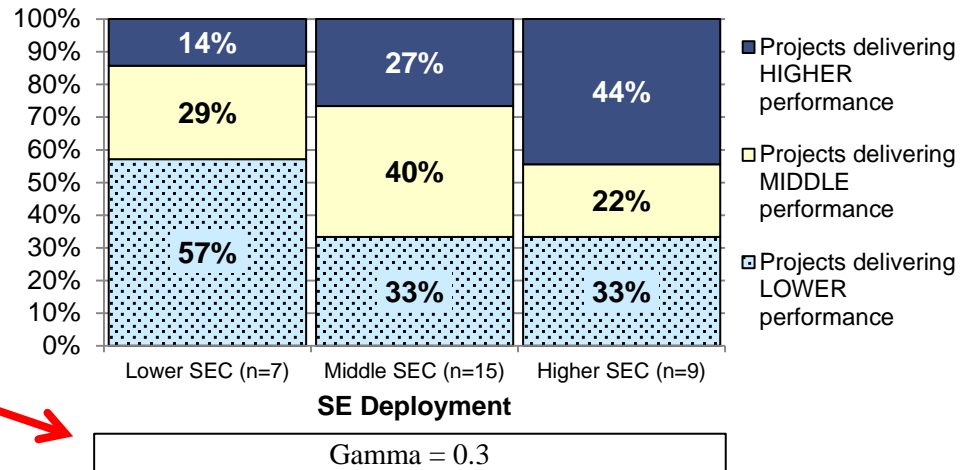
Trade Studies vs. Project Performance

Perf vs. SEC_TRD (defense)

A **Very Strong** relationship between Trade Study activities and Project Performance for Defense Projects

A **Strong** relationship for non-defense projects

Perf vs. SEC_TRD (non-defense)

Summary of Relationships -1

Performance vs. SE Capability

Chart categories (top to bottom): Total SEC, Early SE, Project Planning, Req'ts Dev't & Mg't, Verification, Product Architecture, Configuration Mg't, Trade Studies, Monitor & Control, Validation, Product Integration, Risk Management, Integ Product Teams, Project Challenge, Experience

X-axis: -0.3, -0.2, -0.1, 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7

Band labels: Moderate, Weak, Moderate, Strong, Very Strong

Legend: ■ DEF   ⊠ NonD

Summary of Relationships -2

SYSTEMS ENGINEERING EFFECTIVENESS (Performance vs. SE Deployment)

KEY
- DEF
- Non-DEF

STRENGTH OF Perf vs. SEC RELATIONSHIP
- Weak
- Moderate
- Strong
- Very Strong

Chart axes: Total SEC, Early SE, Verification, Project Planning, Req'ts Dev't & Mg't, Product Integration, Monitor & Control, Validation, Configuration Mg't, Product Architecture, Trade Studies, Risk Management, Integ Product Teams

Scale: 0.00, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70

Next Steps: Investigate the differences between SE deployment / effectiveness in defense and non-defense domains to find "transplantable" best practices

Questions for Further Study

On non-defense projects, <u>why</u> are SE activities in Requirements, Architecture, Risk Management, and Verification more effective than those on defense-related projects?

On defense projects, <u>why</u> are SE activities in Trade Studies, IPTs, and Project Monitoring and Control more effective than those on non-defense projects?

<u>Why</u> is the relationship between Project Challenge and Project Performance stronger for non-defense projects?

<u>Why</u> is the relationship between Prior Experience and Project Performance stronger for non-defense projects?

SEI – Your Resource for Software and Systems Engineering

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27-Oct-2014   19
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BACK UP

References

Elm, J.; Goldenson, D.; El Emam, K.; Donatelli, N.; Neisa, A. "*A Survey of Systems Engineering Effectiveness – Initial Results*". Carnegie Mellon University; Pittsburgh, PA. 2007 (available at http://resources.sei.cmu.edu/library/asset-view.cfm?assetid=8493)

Elm, J.; Goldenson, D. "**The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey**". Carnegie Mellon University; Pittsburgh, PA 2012 (available at http://resources.sei.cmu.edu/library/asset-view.cfm?assetid=34061)

Elm, J.; Goldenson, D. "**The Business Case for Systems Engineering Study: Detailed Response Data**". Carnegie Mellon University; Pittsburgh, PA 2012 (available at http://resources.sei.cmu.edu/library/asset-view.cfm?assetid=73582)

Elm, J. "**The Business Case for Systems Engineering Study: Assessing Project Performance from Sparse Data**". Carnegie Mellon University; Pittsburgh, PA 2012 (available at http://resources.sei.cmu.edu/library/asset-view.cfm?assetid=34055)

Elm, J.; Goldenson, D. "**The Business Case for Systems Engineering: Comparison of Defense Domain and Non-Defense Projects**". Carnegie Mellon University; Pittsburgh, PA 2014 (available at http://resources.sei.cmu.edu/library/asset-view.cfm?assetid=?????)

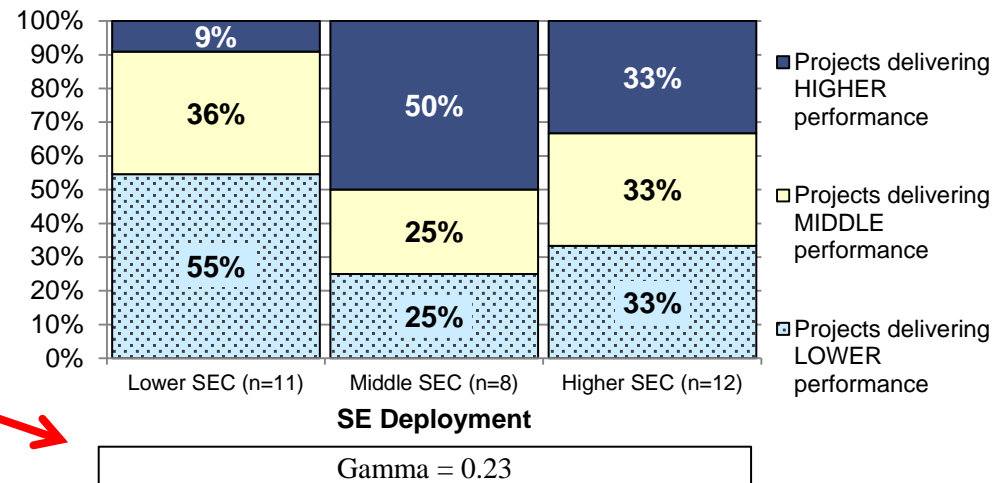# IPT Utilization vs. Project Performance

Perf vs. SEC_IPT (defense)

Gamma = 0.32
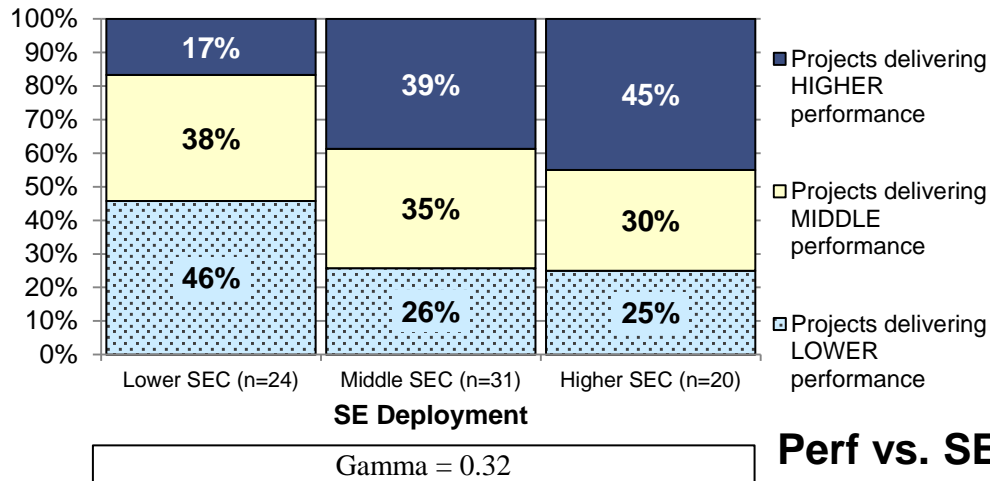
A **Strong** relationship between IPT Utilization and Project Performance for Defense Projects
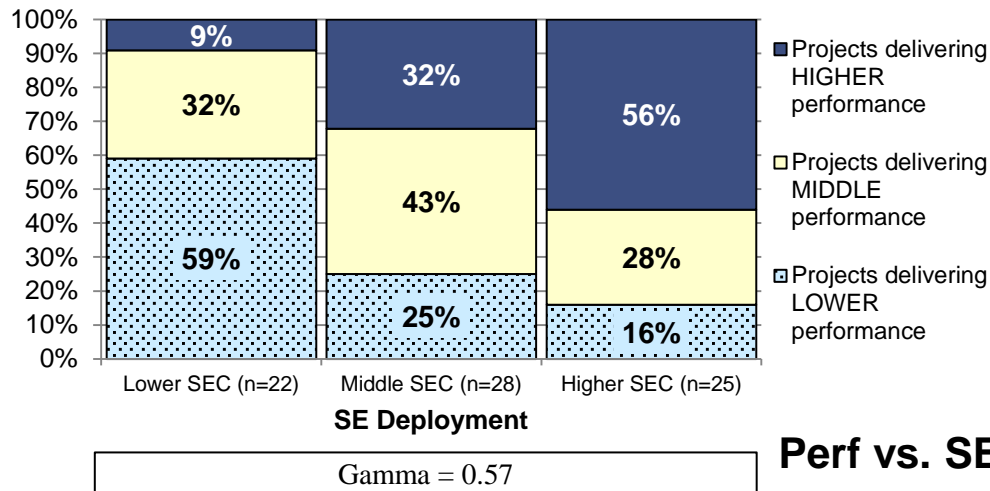
A **Moderate** relationship for non-defense projects
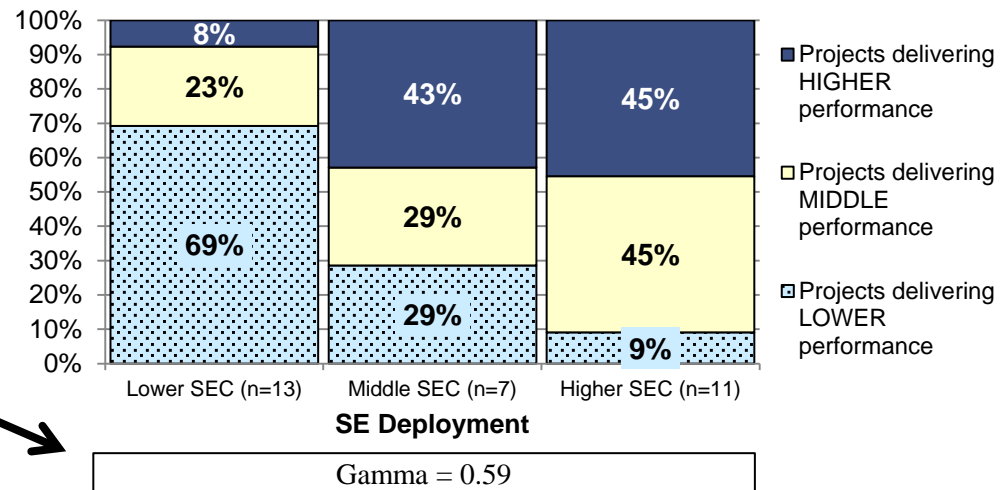
Perf vs. SEC_IPT (non-defense)

Gamma = 0.23

Project Planning vs. Project Performance

Perf vs. SEC_PP (defense)

Legend:
- ■ Projects delivering HIGHER performance
- □ Projects delivering MIDDLE performance
- ▨ Projects delivering LOWER performance

Lower SEC (n=22): 9%, 32%, 59%
Middle SEC (n=28): 32%, 43%, 25%
Higher SEC (n=25): 56%, 28%, 16%

SE Deployment

Gamma = 0.57

A **Very Strong** relationship between Project Planning activities and Project Performance for both Defense and non-Defense Projects

Perf vs. SEC_PP (non-defense)

Legend:
- ■ Projects delivering HIGHER performance
- □ Projects delivering MIDDLE performance
- ▨ Projects delivering LOWER performance

Lower SEC (n=13): 8%, 23%, 69%
Middle SEC (n=7): 43%, 29%, 29%
Higher SEC (n=11): 45%, 45%, 9%

SE Deployment

Gamma = 0.59

Verification vs. Project Performance
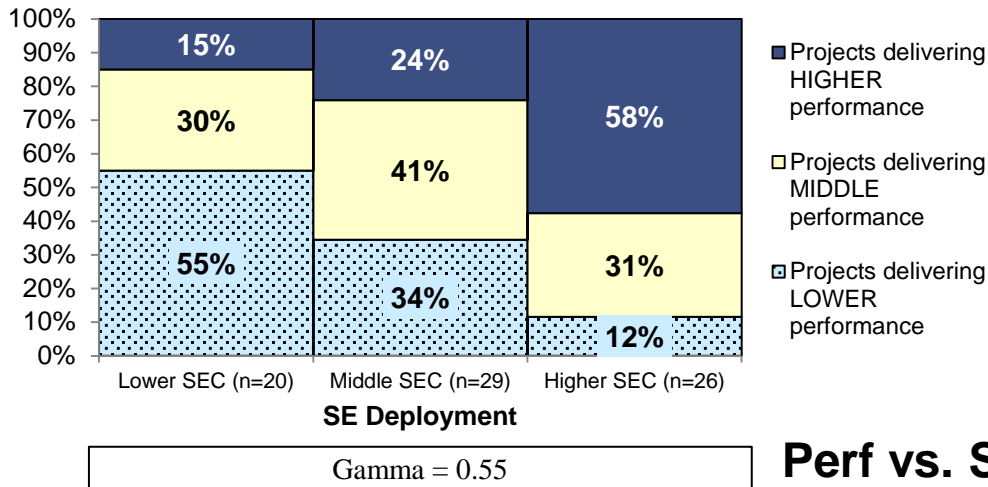
Perf vs. SEC_VER (defense)

Gamma = 0.55

A **Very Strong** relationship between Verification activities and Project Performance for both Defense and non-Defense Projects

Perf vs. SEC_VER (non-defense)

Gamma = 0.64

Validation vs. Project Performance

Perf vs. SEC_VAL (defense)

Legend
■ Projects delivering HIGHER performance
□ Projects delivering MIDDLE performance
▦ Projects delivering LOWER performance

Gamma = 0.45

A **Very Strong** relationship between Validation activities and Project Performance for both Defense and non-Defense Projects

Perf vs. SEC_VAL (non-defense)

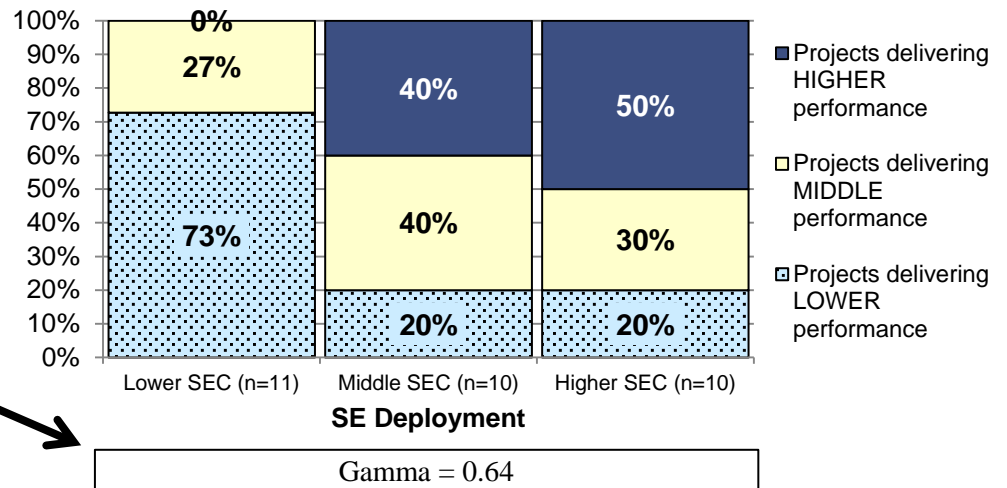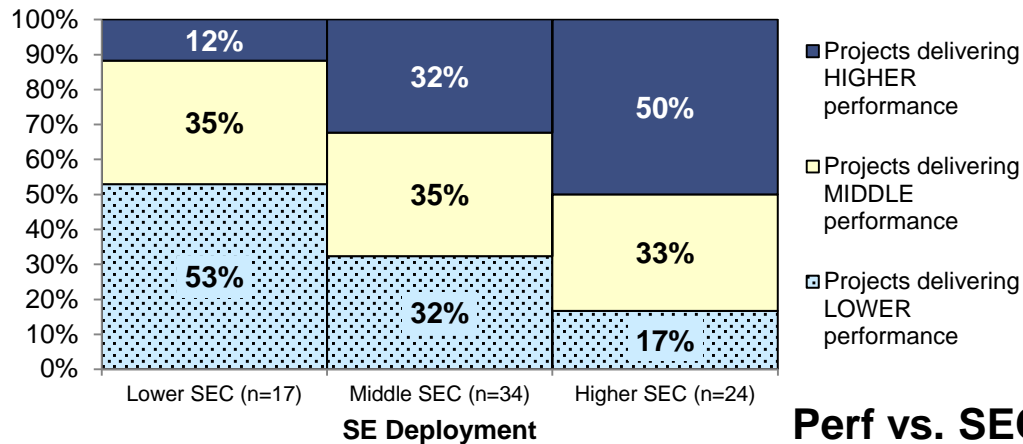| Legend |
|--------|
| ■ Projects delivering HIGHER performance |
| □ Projects delivering MIDDLE performance |
| ▦ Projects delivering LOWER performance |

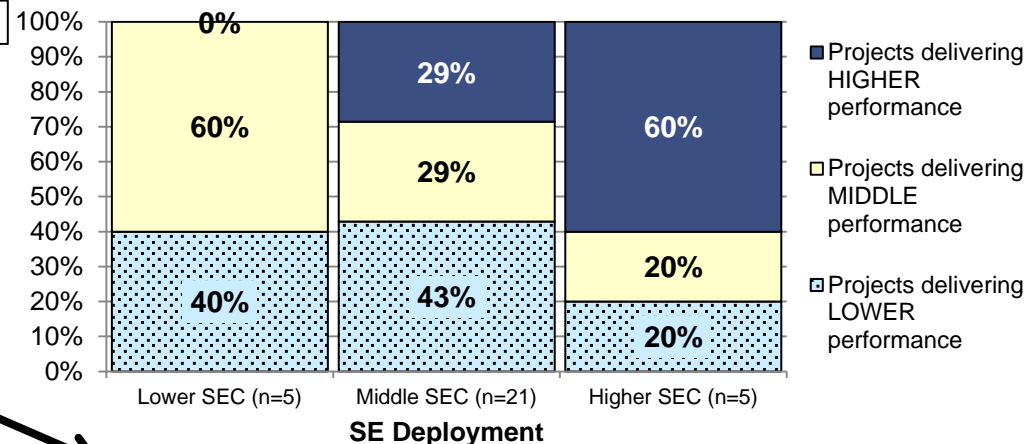Gamma = 0.47

Product Integration vs. Project Performance

Perf vs. SEC_PI (defense)

Gamma = 0.45

A **Very Strong** relationship between Product Integration activities and Project Performance for both Defense and non-Defense Projects
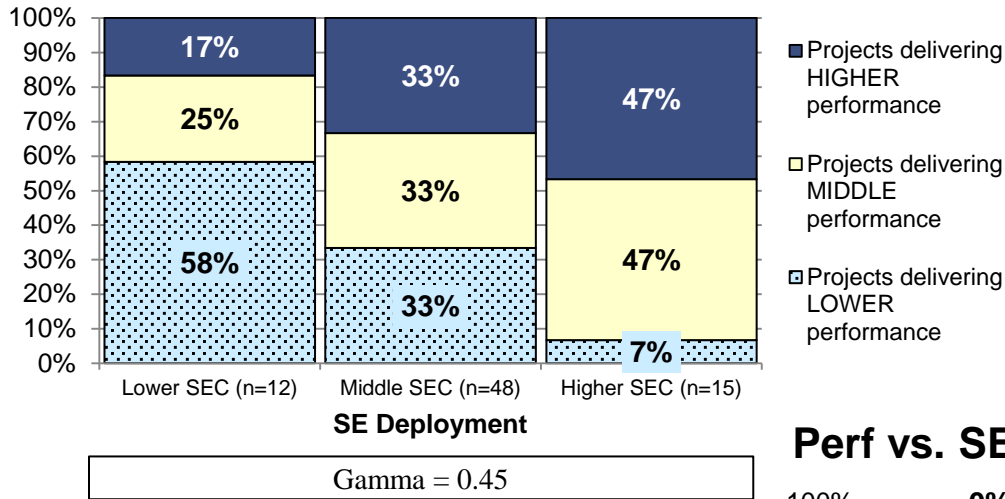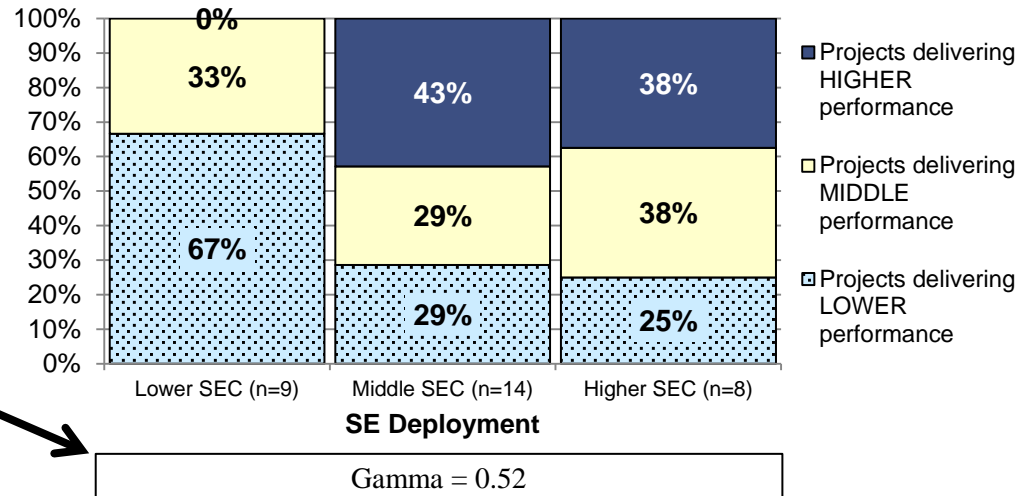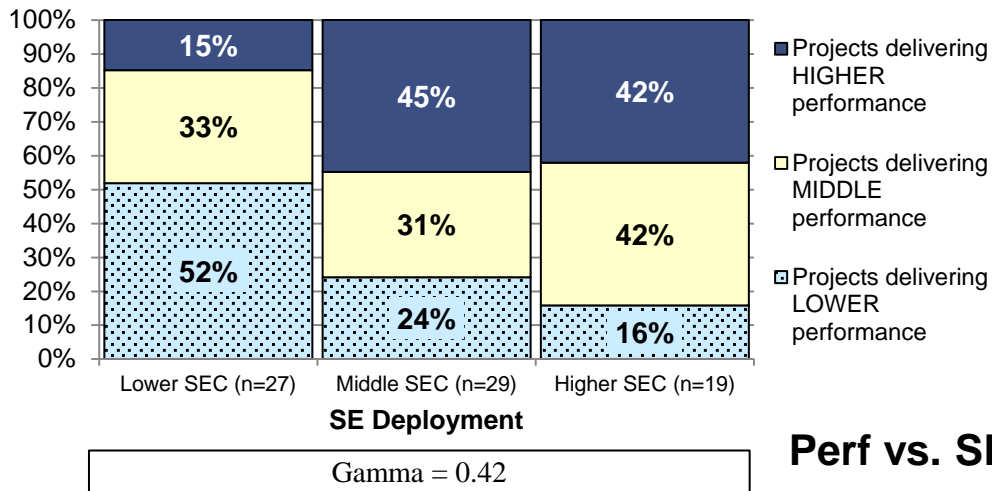
Perf vs. SEC_PI (non-defense)

Gamma = 0.52

Configuration Mg't vs. Project Performance

Perf vs. SEC_CM (defense)

Legend:
- ■ Projects delivering HIGHER performance
- □ Projects delivering MIDDLE performance
- ▥ Projects delivering LOWER performance

Bars (SE Deployment):
- Lower SEC (n=27): 15% / 33% / 52%
- Middle SEC (n=29): 45% / 31% / 24%
- Higher SEC (n=19): 42% / 42% / 16%

Gamma = 0.42

A **Very Strong** relationship between Configuration Management activities and Project Performance for both Defense and non-Defense Projects

Perf vs. SEC_CM (non-defense)

Legend:
- ■ Projects delivering HIGHER performance
- □ Projects delivering MIDDLE performance
- ▥ Projects delivering LOWER performance

Bars (SE Deployment):
- Lower SEC (n=12): 8% / 33% / 58%
- Middle SEC (n=11): 36% / 27% / 36%
- Higher SEC (n=8): 50% / 38% / 13%

Gamma = 0.47
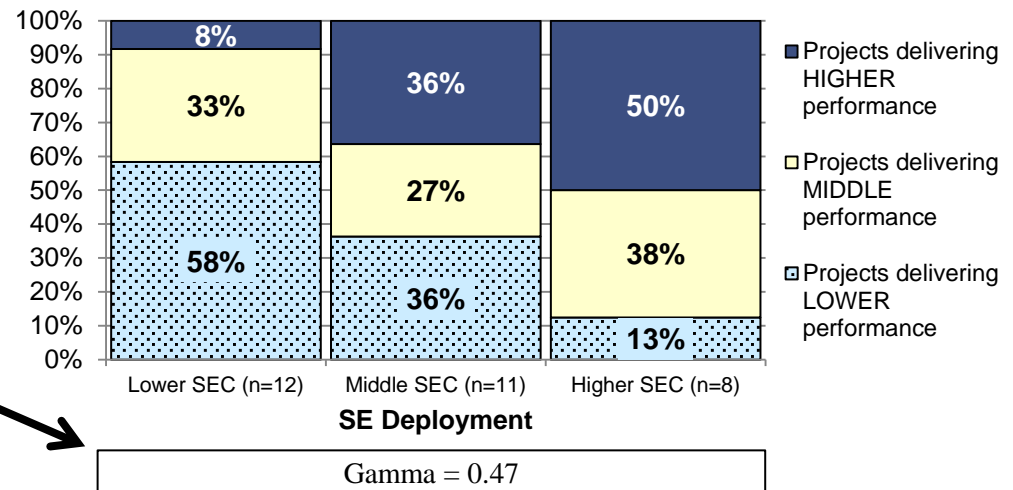
Monitoring & Control vs. Project Performance

Perf vs. SEC_PMC (defense)

- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Gamma = 0.48
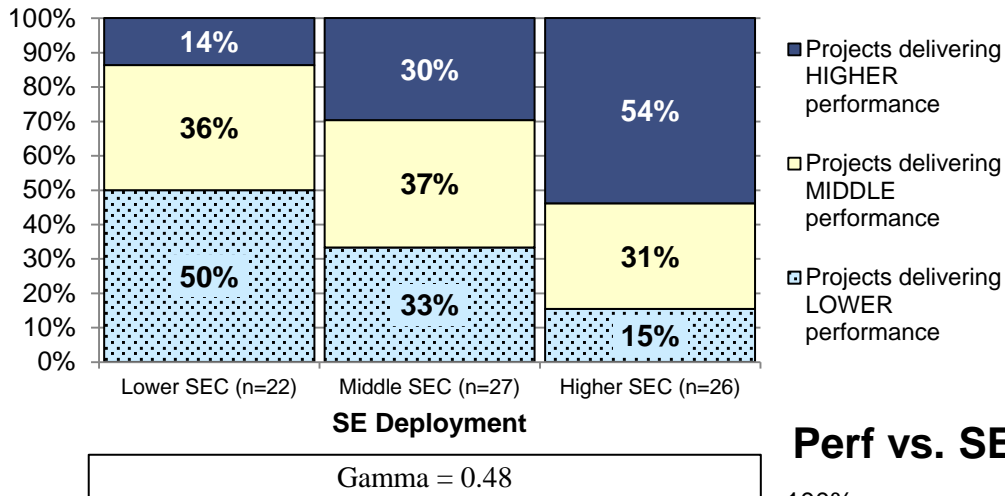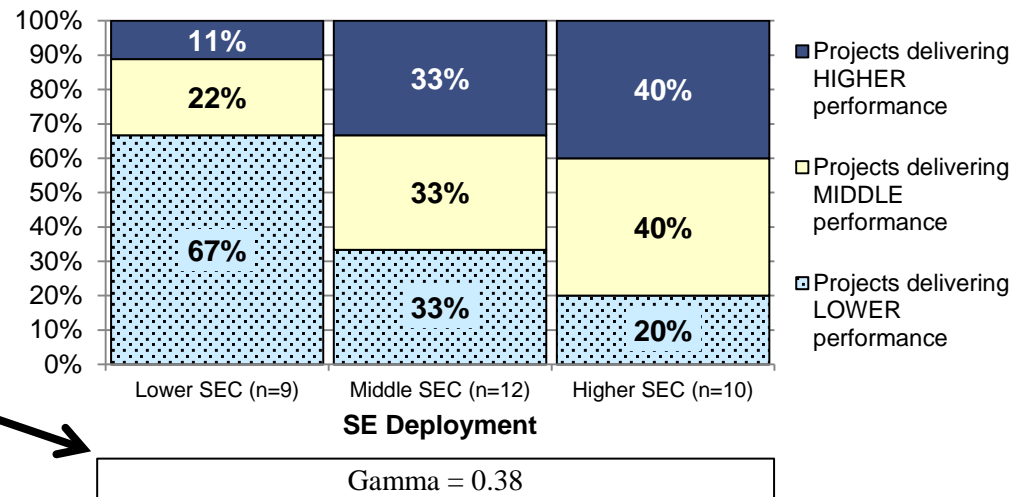
A **Very Strong** relationship between Project Monitoring and Control activities and Project Performance for Defense Projects

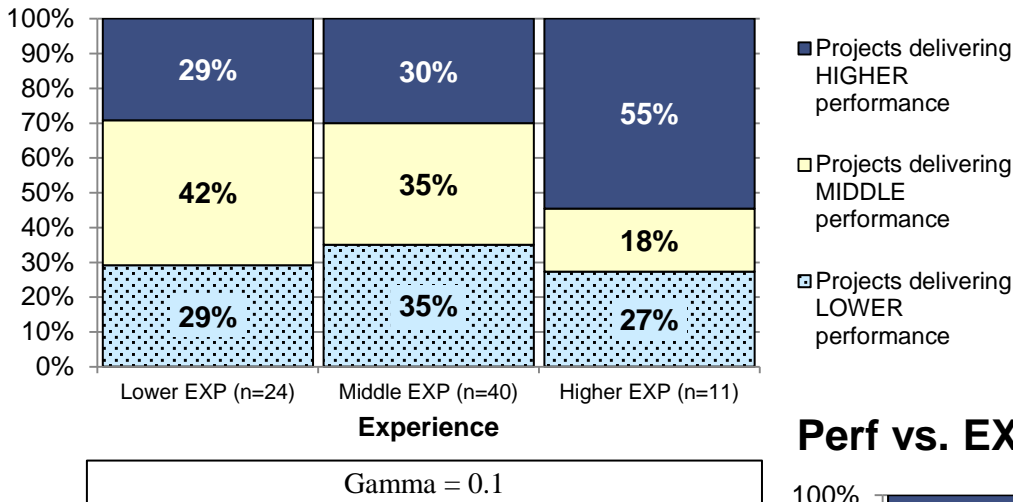A **Strong** relationship for non-defense projects

Perf vs. SEC_PMC (non-defense)

- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Gamma = 0.38

Prior Experience vs. Project Performance

Perf vs. EXP (defense)

Legend:
- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Chart values:
- Lower EXP (n=24): HIGHER 29%, MIDDLE 42%, LOWER 29%
- Middle EXP (n=40): HIGHER 30%, MIDDLE 35%, LOWER 35%
- Higher EXP (n=11): HIGHER 55%, MIDDLE 18%, LOWER 27%

Experience

Gamma = 0.1
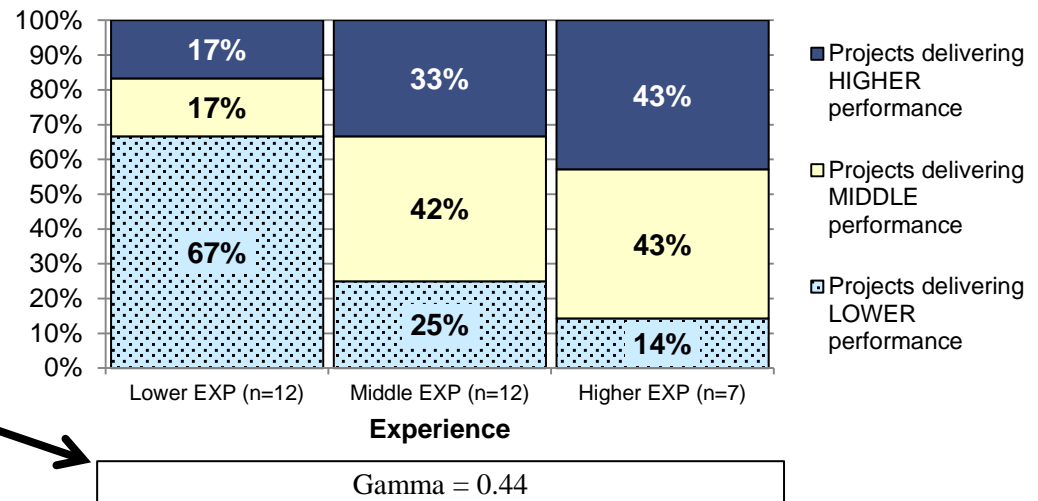
A **Weak** relationship between Prior Experience and Project Performance for Defense Projects

A **Strong** relationship for non-defense projects

Perf vs. EXP (non-defense)

Legend:
- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Chart values:
- Lower EXP (n=12): HIGHER 17%, MIDDLE 17%, LOWER 67%
- Middle EXP (n=12): HIGHER 33%, MIDDLE 42%, LOWER 25%
- Higher EXP (n=7): HIGHER 43%, MIDDLE 43%, LOWER 14%

Experience

Gamma = 0.44

Project Challenge vs. Project Performance

Perf vs. PC (defense)

A **Weak Negative** relationship between Project Challenge and Project Performance for Defense Projects
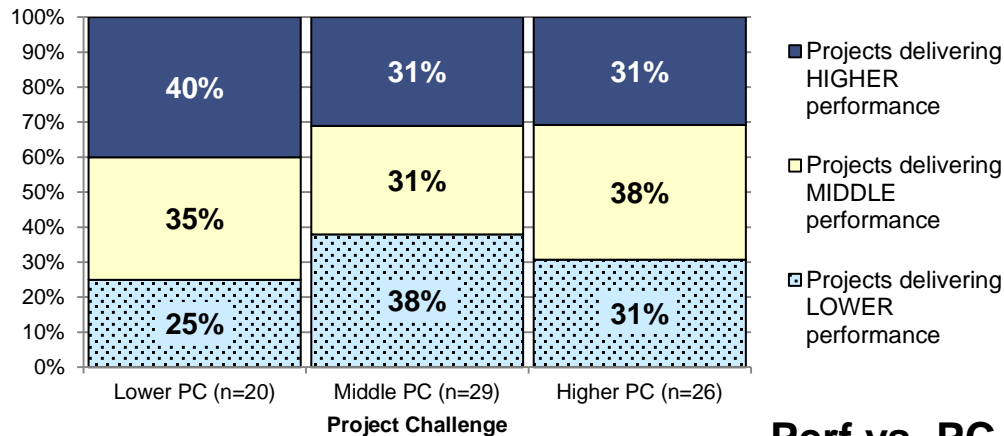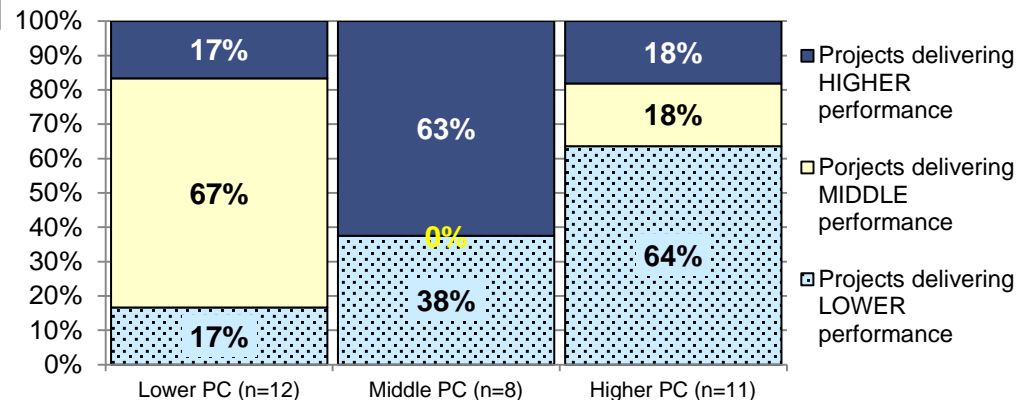
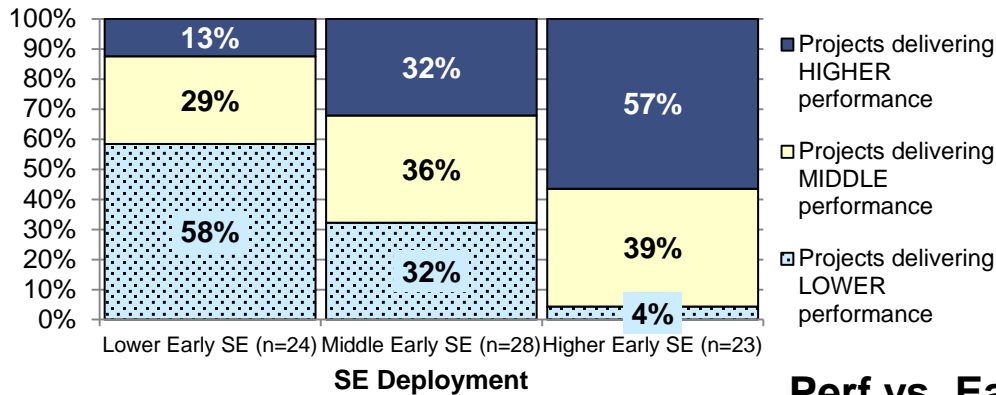A **Moderate Negative** relationship for non-defense projects

Perf vs. PC (Non-defense)

Early SE vs. Project Performance

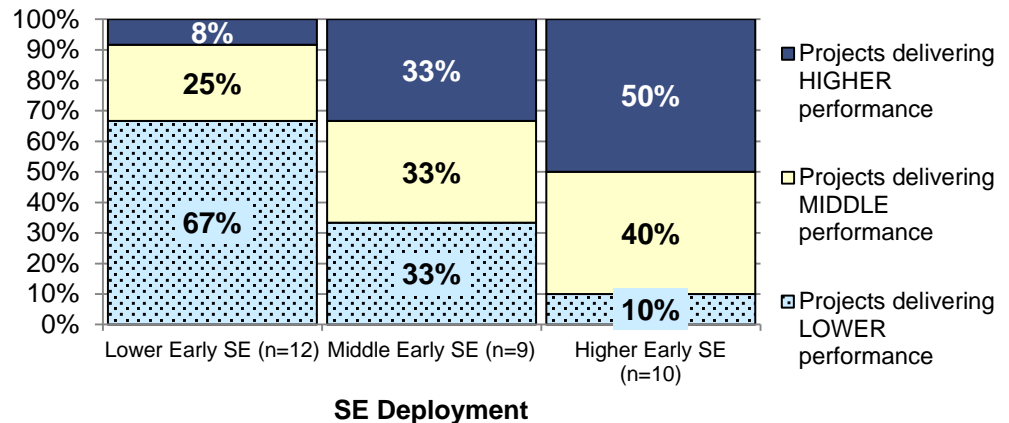## Perf vs. Early_SE (defense)

SE Deployment		
Lower Early SE (n=24)	Middle Early SE (n=28)	Higher Early SE (n=23)

- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Lower Early SE: 13% HIGHER, 29% MIDDLE, 58% LOWER
Middle Early SE: 32% HIGHER, 36% MIDDLE, 32% LOWER
Higher Early SE: 57% HIGHER, 39% MIDDLE, 4% LOWER

Gamma = 0.61

A **Very Strong** relationship between Early SE activities and Project Performance for both Defense and non-Defense Projects

Early SE

- Project Planning
- Requirements Development
- Trade Studies
- Product Architecture

Perf vs. Early_SE (non-defense)

SE Deployment		
Lower Early SE (n=12)	Middle Early SE (n=9)	Higher Early SE (n=10)

- Projects delivering HIGHER performance
- Projects delivering MIDDLE performance
- Projects delivering LOWER performance

Lower Early SE: 8% HIGHER, 25% MIDDLE, 67% LOWER
Middle Early SE: 33% HIGHER, 33% MIDDLE, 33% LOWER
Higher Early SE: 50% HIGHER, 40% MIDDLE, 10% LOWER

Gamma = 0.62